Assimilation of Synthetic-Aperture Radar Data into Navy Wave Prediction Models

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LONG-TERM GOAL

To develop methods utilizing synthetic aperture radar (SAR) data to improve predictions for the littoral zone obtained from Navy wave forecasting models — in this case the SWAN model of Ris et al. (1995).

OBJECTIVES

There are three basic objectives to this program: (1) to develop a forward prediction capability for the expected value of the SAR-image spectrum, with the SWAN wave-spectrum prediction as input; (2) to develop methods to bring the SWAN-based SAR-spectrum prediction into agreement with satellite-based SAR observations by adjusting the model inputs; and (3) to validate the improvement in the results from the SWAN model against ground-truth data.

APPROACH

The accuracy of the predictions obtained from the SWAN model is limited by (among other things) inaccuracies in the specification of the model inputs (initial conditions, boundary conditions, and forcing). The information contained in SAR images of ocean waves can potentially be used to improve the predictions, by guiding modifications to the model inputs so as to obtain the best agreement between the observed SAR-image spectrum and the SAR-image spectrum predicted from the wave spectrum output from the SWAN model.

For the calculation of the SAR-image spectrum corresponding to a given SWAN prediction of the wave spectrum, the approaches to be used are the fully nonlinear mapping approach of Hasselmann & Hasselmann (1991). The approach used to bring the predicted SAR-image spectrum into agreement with the observed SAR-image spectrum will rely on the variational framework outlined by LeDimet & Talagrand (1986) which corresponds to the strong-constraint formalism of Bennett (1992). This approach requires the derivation of the adjoint of the SWAN model. The adjoint model equations are forced by the difference between the predicted and observed SAR-image spectra, and their solution yields a 'correction' to the model inputs. This procedure is iterative in nature and is applied until the

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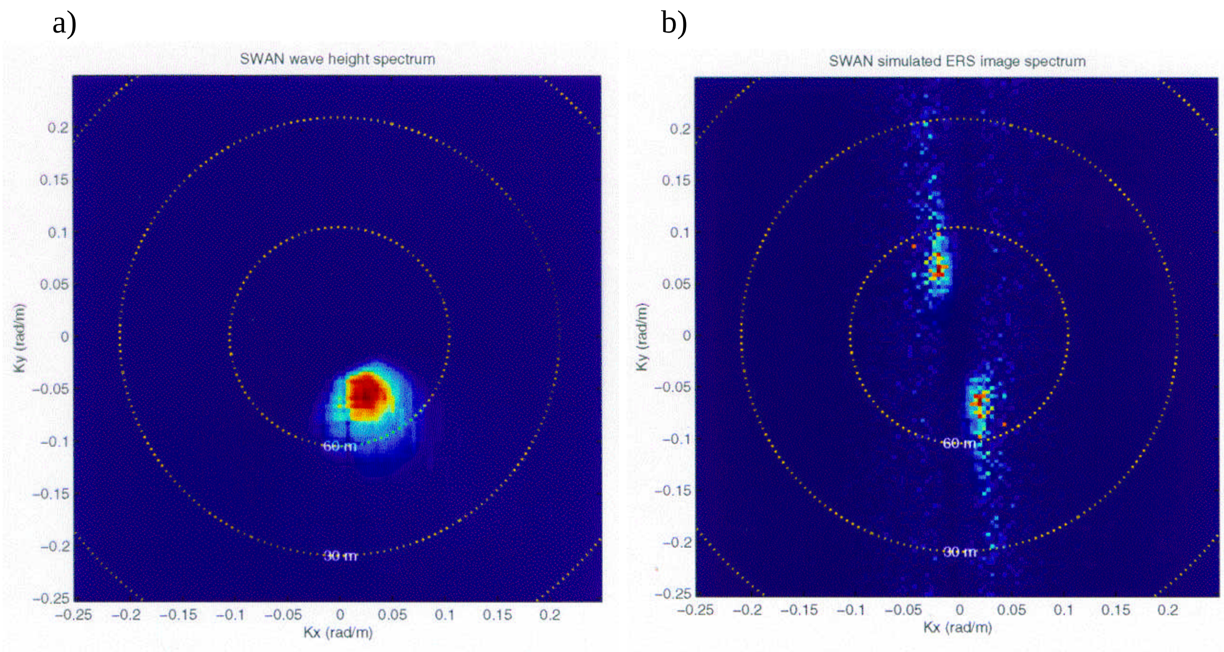

Figure 1 a) SWAN-predicted wave spectrum for October 1994 storm at the Duck FRF.
(b) Modeled ERS SAR-image spectrum using the developed software.

difference is minimized. Validation of the procedure will rely on comparison of model predictions both with and without SAR data assimilation to ground truth data in order to quantify the improvements.

WORK COMPLETED

During FY 98, software implementing the forward SAR model was developed and tested. In addition, the adjoint to the SWAN model was derived and coded. Testing and implementation of the adjoint model will be accomplished in the coming fiscal year.

RESULTS

The main accomplishment of the current fiscal year, in addition to the derivation of the adjoint SWAN model, is the development of SAR spectrum modeling capability. This capability relies on the formulation of Hasselmann & Hasselmann (1991) for the expected value of the SAR-image spectrum, in terms of the expected value of the wave spectrum. This model has been interfaced to the SWAN model; figure 1 shows a sample output wave spectrum from the SWAN model and the corresponding estimated SAR-image spectrum. The conditions correspond to a storm which occurred at the Duck NC Field Research Facility on 14 October 1994. SAR imagery is currently being obtained for this case.

Figure 2 shows comparison of an actual SAR-image spectrum and the expected value of the SAR spectrum estimated from a long-time-averaged wave spectrum. Figure 2 a) shows an ERS2 SAR image of the region including the Duck FRF for 20 November 1996. The swell waves are clearly in evidence in this image. Figure 2 b) shows the directional spectrum as indicated by the FRF 8 m array. (Note the spectrum coordinates are rotated 90° ccw relative to the image coordinates.) Figures 2 c) and d), respectively, show the SAR-image spectrum calculated directly from the image, and estimated from the directional wave spectrum. The directly-calculated SAR-image spectrum shown in figure 2 c) represents a realization of the SAR-image spectrum, while the result shown in figure 2 d) would

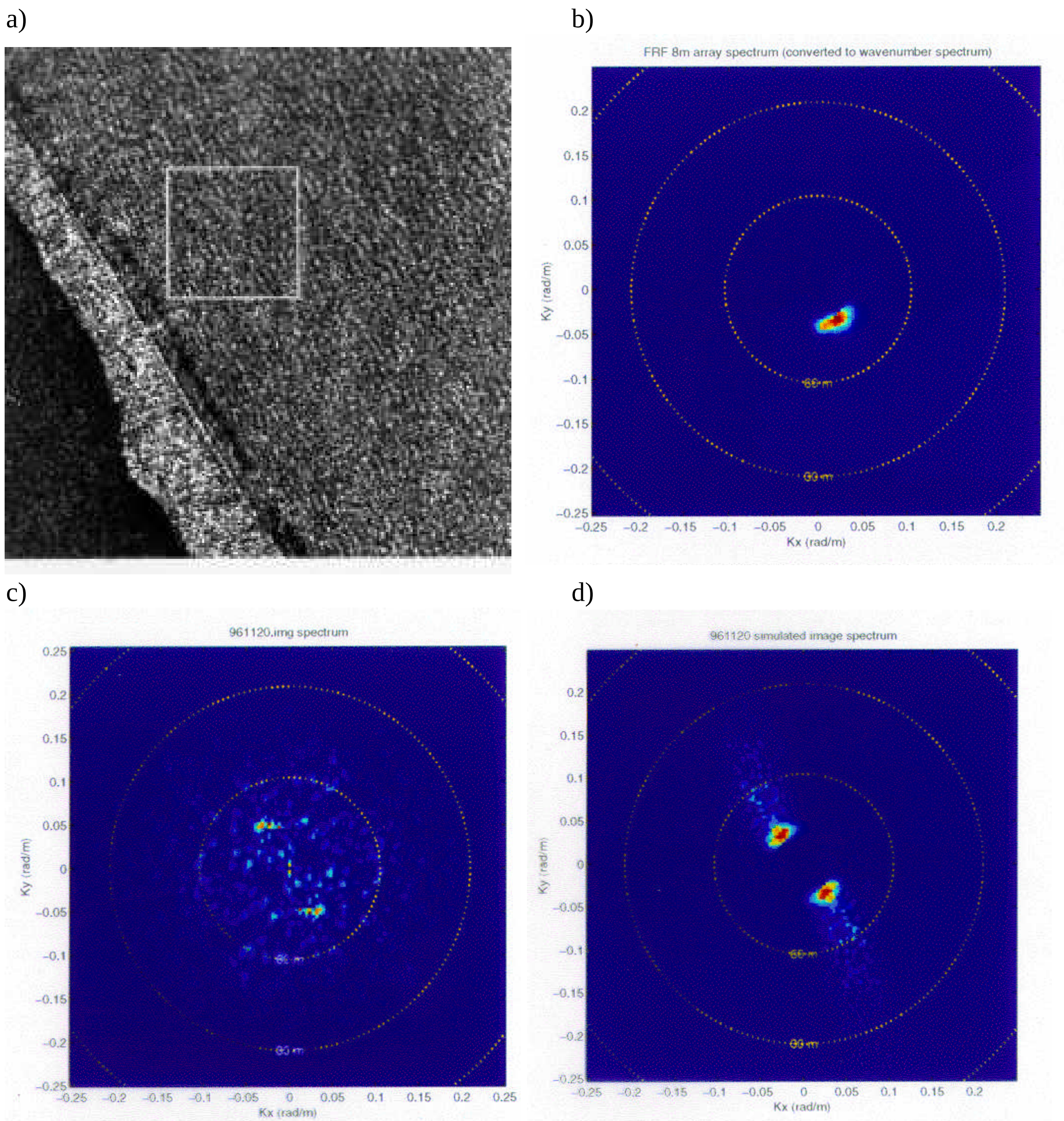

Figure 2 a) ERS-2 SAR image of Duck FRF for 20 November 1996 15:44 GMT. The image is 6.4 km on a side. b) Corresponding three-hour-average wave spectrum from the FRF 8 m array. c) SAR-image spectrum for the 1.6 x1.6 km subset shown in a). d) Modeled SAR image spectrum using the FRF 8 m array spectrum as input. Note the spectrum coordinates are all rotated 90° ccw relative to the image coordinates.

represent the corresponding expected value for the spectrum. While there are differences related to this fact, the apparent dominant wave direction and wavenumber agree quite well between the two images.

IMPACT/APPLICATION

Achieving the overall objectives of the program will result in an improved prediction capability for near-shore waves, allowing readily available remote sensing data to be used effectively. The forward prediction capability for SAR-image spectra, established during this FY, while addressing the overall objectives of the program, is in itself of value. It will enable the use of available SAR data as a 'sanity' check on model predictions.

TRANSITIONS

As the data assimilation capability for the SWAN model is developed during the coming FY, its use may be extended beyond the assimilation of SAR data, to other data types by other participants in the BE effort.

RELATED PROJECTS

This project is related to other efforts under the BE program. Improvements to the SWAN model (in both physical and numerical modeling) being pursued at NRLSSC, NPGS and WES will be included in the assimilation scheme as they are developed.

REFERENCES

Bennett, A.F. 1992 Inverse Methods in Physical Oceanography. Cambridge.

Hasselmann, K. & Hasselmann, S. 1991 On the nonlinear mapping of an ocean-wave spectrum into a synthetic aperture radar image spectrum and its inversion. J. Geophys. Res. **96**, 10,713–10,729.

Le Dimet, F.-X. & Talagrand, O. 1986 Variational algorithms for analysis and assimilation of meteorological observations: theoretical aspects. Tellus **38**A, 97-110.

Ris, R.C., Booij, N. & Holthuijsen, L.H. 1995 SWAN Cycle 1 User Manual. Department of Civil Engineering, Delft University of Technology.